NASA Technical Memorandum 84910

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J. Blair Johnson and Jeff Nelson
NASA Ames Research Center, Dryden Flight Research Facility, Edwards, California 93523

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## SUMMARY

The air-start capability of a secondary engine control (SEC) was tested for a DEEC-equipped F100 engine installed in an F-15 airplane. Two air-start schedules were tested. The first was referred to as the group I schedule; the second, or revised schedule, was the group II start schedule.

Using the group I start schedule, an airspeed of 300 knots was required to ensure successful 40- and 25-percent SEC-mode air starts. If N2 were less than 40 percent, a stall would occur when the start bleeds closed 40 sec after initiation of the air start. All JFS-assisted air starts were successful with the group I start schedule.

For the group II schedule, the time between pressurization and start-bleed closure ranged between 50 and 72 sec depending on altitude. All air starts were successful above 225 knots giving a 75-knot reduction in required airspeed for a successful air start. Spooldown air starts of 40 percent were successful at 200 knots at altitudes up to 10,650 m and at 175 knots at altitudes up to 6100 m. Idle rpm was lower than the desired 65 percent for air starts at higher altitudes and lower airspeeds. All JFS-assisted air starts were successful.

## INTRODUCTION

With the increase of aircraft-engine-control complexity and the desire for improved engine performance, full-authority, digital-engine-control systems are being developed. One example is the digital electronic engine control (DEEC) system. As a backup to the digital control system, the DEEC incorporates an independent secondary engine control. One important factor is the ability of this secondary engine-control system to perform a successful air start over a wide flight envelope, particularly, near the maximum glide and maximum range airspeeds of the aircraft. The NASA Ames Research Center's Dryden Flight Research Facility has recently tested an F100-PW-100 turbofan engine equipped with a DEEC in an F-15 airplane (ref. 1). The hydromechanical secondary engine control (SEC) is contained in the same unit as the DEEC main-engine fuel-metering valves. Because of their importance to the safe operation of aircraft, especially single-engine aircraft, the air-start capabilities of the DEEC and SEC were investigated. DEEC air-start results are summarized in reference 2. This report gives the results of the SEC air-start capability and includes the air-start logic, instrumentation, and test procedures.

## NOMENCLATURE

| | |
|---|---|
| AJ | jet primary nozzle area |
| CIVV | compressor inlet variable vane |
| DEEC | digital electronic engine control |
| FTIT | fan turbine inlet temperature, °C |
| JFS | jet fuel starter |

| | |
|---|---|
| M | Mach number |
| N1 | fan rotor rpm, percent |
| N2 | core rotor rpm, percent (100 percent N2 = 14,000 rpm) |
| PAB | augmentor static pressure |
| PB | burner pressure |
| PLA | power lever angle |
| PS2 | fan inlet static pressure |
| PS2C | compensated fan inlet static pressure |
| PT6M | turbine discharge total pressure |
| RCVV | rear compressor variable vane |
| SEC | secondary engine control |
| T | air-start time from pressurization to idle, sec |
| TT2 | engine inlet total temperature |
| VC | calibrated airspeed, knots |

## DESCRIPTION OF APPARATUS

### Test Aircraft

The F-15 airplane is a high-performance, twin-engine fighter capable of speeds up to Mach 2.5. It has a high-mounted, sweptback wing, twin vertical stabilizers, and a horizontal stabilator (fig. 1). The engine inlets are of two-dimensional, horizontal-ramp design. The inlets utilize external compression with three ramps and feature variable capture area by rotating the inlet about a transverse hinge point at the lower cowl lip. The ramps and bypass door are automatically scheduled by the air-inlet controller.

### Test Engine

The F-100-PW-100 engine is a low bypass ratio (0.8), twin-spool, afterburning turbofan (fig. 2). The three-stage fan is driven by a two-stage, low-pressure turbine. The ten-stage, high-pressure compressor is driven by a two-stage, high-pressure turbine. The engine incorporates compressor inlet variable vanes (CIVVs) and rear compressor variable vanes (RCVVs) to achieve high performance over a wide range of power settings; a compressor bleed is used only for starting. Continuously variable-thrust augmentation is provided by a mixed-flow afterburner, which is exhausted through a variable area convergent-divergent nozzle. The test results in this report were obtained on engine S/N P680063. This engine had been updated to an F100(3) configuration and incorporated a proximate splitter. The proximate splitter is the flow divider between the fan and core stream that extends forward to the fan discharge.

## Secondary Engine Control

The secondary engine control is hydromechanical and designed to control main-burner fuel flow (WFGG), RCVV position, and start-bleed position. In case of a DEEC failure, control is transferred automatically to the SEC. In the SEC mode, the CIVVs go to the full-camber position, the nozzle closes, and augmentation is cancelled. The SEC receives inputs from the fan inlet static pressure (PS2), fan inlet total temper-ature (TT2), power lever angle (PLA), and RCVV position. There are no rpm (N1, N2) or fan turbine inlet temperature (FTIT) inputs to the SEC. A block diagram of the SEC logic is shown in figure 3.

## SEC Air-Start Logic

The SEC air-start logic is an automatic schedule derived from a cam in the SEC. The start cam, activated when the power lever is moved from the cut-off to idle position, schedules a percentage of the idle fuel flow biased by PS2. During the SEC start, the RCVVs and compressor-start bleeds are held in the cambered and open positions, respectively. Figure 4 presents a revised start schedule (group II) used currently, as well as the previous start schedule (group I). The most notable differences are the shapes of the fuel-flow schedule curves and the elapsed time to RCVV release and start-bleed closure. For the revised schedule, the initial fuel flow is slightly higher, and the elapsed time to start-bleed closure and RCVV release is dependent on PS2 – the old schedule released the RCVV and closed the start bleeds after approximately 40 sec for all values of PS2. If the fuel flow is too great for a given situation, the compressor will stall and a hot start will result. However, if the fuel flow is too low, preventing the engine from increasing core rpm, a stall will occur when the start bleeds close.

## Jet Fuel Starter

The jet fuel starter (JFS) is a small auxiliary gas-turbine power unit which can be coupled to the F100 engine. The JFS is used to accelerate the compressor for engine starting on the ground and in flight. In flight, JFS use is limited to altitudes below 6100 m. The JFS is engaged manually by the pilot and disengages automatically when the compressor speed (N2) reaches 50 percent on a start.

# INSTRUMENTATION

Figure 5 shows the instrumentation and fuel system on the DEEC test engine. The instrumentation installed measures pressures, temperatures, rotor speed, fuel flow, and variable vane positions. In addition, a serial digital data stream from the DEEC computer was recorded. Aircraft parameters measured included angle of attack and sideslip as well as noseboom total and static pressures. Data were recorded on a pulse code modulation (PCM) system. Parameters of interest for this report were sampled at 20 samples per second. The various parameters were filtered before digitization by the PCM system to prevent aliasing errors. The data were recorded on a tape recorder on the F-15 and were also telemetered to the ground for recording and for real-time analysis and display.

## TEST PROCEDURES

Two types of air starts were performed to evaluate the air-start capability of the SEC. They were the spooldown and JFS-assisted air starts. A spooldown air start is one in which the compressor rotor is decelerating (spooling down) as the air start is initiated. Before the spooldown air-start sequence was started, the engine was shut down from the military power setting. The engine core was allowed to decelerate (spooldown) to a specified percentage of the maximum core speed (N2) before pressurization, typically 40 and 25 percent. The air start was initiated when the power lever was moved from the cut-off position to the idle position, pressurizing the fuel system and activating the ignitor. The SEC-start timer begins and schedules the fuel flow to the combustor. The fuel fills the fuel manifolds and reaches the combustor approximately 10 sec later. The fuel is ignited (light) and the core rpm accelerates to idle speed (idle speed = 65-percent N2). When the start timer elapses, the compressor-start bleeds close and the RCVVs are allowed to follow their normal schedule.

The JFS-assisted air start was accomplished by engaging the JFS to the core at any engine speed below 30-percent N2 and prior to the pressurization step. It accelerated the engine core and was disengaged at 50-percent N2.

For data analysis, the time for an air start is defined to be the time from pressurization to idle N2.

## TEST RESULTS

### Air Starts With Group I Schedules

Figure 6 presents time histories of successful spooldown air starts using the group I start schedules at an airspeed of 310 knots and an altitude of 4600 m. A 40-percent spooldown air start is shown in figure 6(a) and a 25-percent spooldown air start in figure 6(b). In both cases, start-bleed closure and RCVV release occurred 40 sec after pressurization as indicated by the drop in FTIT. However, N2 was approx-imately 43 percent and still increased to an idle condition. Although these starts were successful, it is apparent that the start timer elapsed before the start was complete.

Figure 7 presents spooldown air starts at the same altitude of 4600 m but at a slower airspeed of 280 knots. Figures 7(a) and 7(b) show 40- and 25-percent spooldown air starts, respectively. Both of these cases resulted in a stall rather than a successful air start. The stalls occurred 40 sec after pressurization at rotor speeds of approximatley 38 percent, when the start bleeds closed and the RCVV released — effectively lowering the stall margin. In both cases, the pilot returned the throttle to cut-off when the stall was indicated by the rise in FTIT and decreasing N2. The stalls occurred at the lower airspeeds because the rotor acceleration was slower due to the lower inlet pressure and fuel flow. In general, if N2 were less than 40 percent when the start timer elapsed, stalls would occur.

JFS-assisted air starts were made at airspeeds of 250, 200, and 175 knots at 6100 m. All were successful. The JFS assist permitted a rapid increase in N2 and avoided the stalls that occurred without the JFS assist.

Figure 8 presents a flight summary showing flight conditions for successful and unsuccessful 40- and 25-percent and JFS-assisted air starts using the group I start schedules. This figure indicates that the SEC-mode spooldown air starts below 300 knots, at any flight altitude, were unsuccessful except for a 40-percent spooldown at 275 knots and 7600 m. A success line that divides the successful air starts from the unsuccessful air starts is shown.

Also shown is a success line established during altitude facility testing at the Arnold Engineering Development Center (ref. 3). SEC-mode starts were successful at airspeeds that were approximately 50 knots lower than in flight. However, there were no horsepower or bleed extractions during the altitude facility testing.

Figure 9 shows the air-start times for successful SEC air starts with the group I start schedules as a function of airspeed and altitude. Figures 9(a), 9(b), and 9(c) present air-start times for 40- and 25-percent and JFS-assisted air starts, respectively. With the group I schedule, the time required for successful 40- and 25-percent spooldown air starts is primarily a function of airspeed, with no significant altitude effects. Air-start times were generally in the 50- to 60-sec range. JFS air-start times ranged from 40 to 65 sec.

## Air Starts With Group II Schedules

Figure 10 presents air-start time histories for spooldown air starts using the revised start schedule (group II). Spooldown air starts of 40 and 25 percent, at similar flight conditions to those time histories shown for the group I schedule, are shown in figures 10(a) and 10(b). Even though the group I schedule provided for a successful start at these conditions, the group II schedule closed the start bleeds later, took approximately 63 sec from pressurization to bleed closure, and allowed N2 to accelerate to values in excess of 63 percent — a near idle condition.

Figure 11 presents air starts at 200 knots and 4600 m using the group II schedule. Figures 11(a) and 11(b) show that for the 40- and 25-percent spooldown starts, the group II schedule allowed successful starts where they would have been unsuccessful using the group I schedules. Although these air starts were termed successful, the idle N2 values were approximately 60 percent, which is lower than the desired idle speed of 65 percent. The pilot would have to advance the throttle slowly while accelerating the engine from 60 to 65 percent.

Figure 12 presents a time history of an unsuccessful 40-percent spooldown air start at 175 knots and 7600 m. In this case, the scheduled fuel flow was too low to accelerate the core to a sufficient speed before the bleeds closed, resulting in a stall.

A JFS-assisted air-start time history is presented in figure 13. It shows the relatively rapid increase in N2 even at an airspeed as low as 150 knots. The air start is again termed successful, but the idle speed of 50 percent is much lower than desired. The pilot would have to advance the throttle very slowly to increase N2 to the desired idle rpm of 65 percent.

To summarize the effectiveness of the group II schedule, figure 14 shows a summary of successful and unsuccessful 40- and 25-percent spooldown air starts. All starts attempted above 225 knots were successful. Spooldown air starts of 40 percent were successful above 200 knots at all altitudes tested and were successful at 175 knots below 6100 m.

The success boundary established from the group I summary graph shows the improvement gained by revising the start schedule. Essentially, the revision decreases the airspeed required for a successful SEC-mode air start by approximately 75 knots.

Figure 15 presents the time required for a successful air start, with the group II schedule, versus airspeed and altitude. For both 40- and 25-percent spooldown air starts (figs. 15(a) and 15(b)), the revision caused the air-start time to become more altitude dependent rather than totally airspeed dependent as was the case with the group I schedule. This is a result of biasing the time to start-bleed closure by PS2. Also shown are air starts in which the idle rpm was less than the desired 65 percent.

Figure 15(c) presents the time required versus airspeed and altitude for JFS-assisted air starts with the group II schedules; and as was the case with the group I schedules, all JFS-assisted air starts were successful.

## CONCLUDING REMARKS

The DEEC secondary engine control air-start capability was tested in an F-15 airplane for the group I and group II start schedules.

For the group I schedule, an airspeed of 300 knots was required to ensure successful 40- and 25-percent SEC-mode air starts. If N2 were less than 40 percent, a stall would occur when the start bleeds closed 40 seconds after initiation of the air start. All JFS-assisted air starts were successful with the group I start schedule.

For the group II schedule, the time between pressurization and start-bleed closure ranged between 50 and 72 sec depending on altitude. All air starts were successful above 225 knots giving a 75-knot reduction in required airspeed for a successful air start. Spooldown airstarts of 40 percent were successful at 200 knots at altitudes up to 10,650 m, and were successful at 175 knots at altitudes up to 6100 m. All JFS-assisted air starts were successful. Idle rpm was lower than the desired 65 percent for air starts at higher altitudes and lower airspeeds.

*Ames Research Center*
*Dryden Flight Research Facility*
*National Aeronautics and Space Administration*
*Edwards, California 93523, March 23, 1983*

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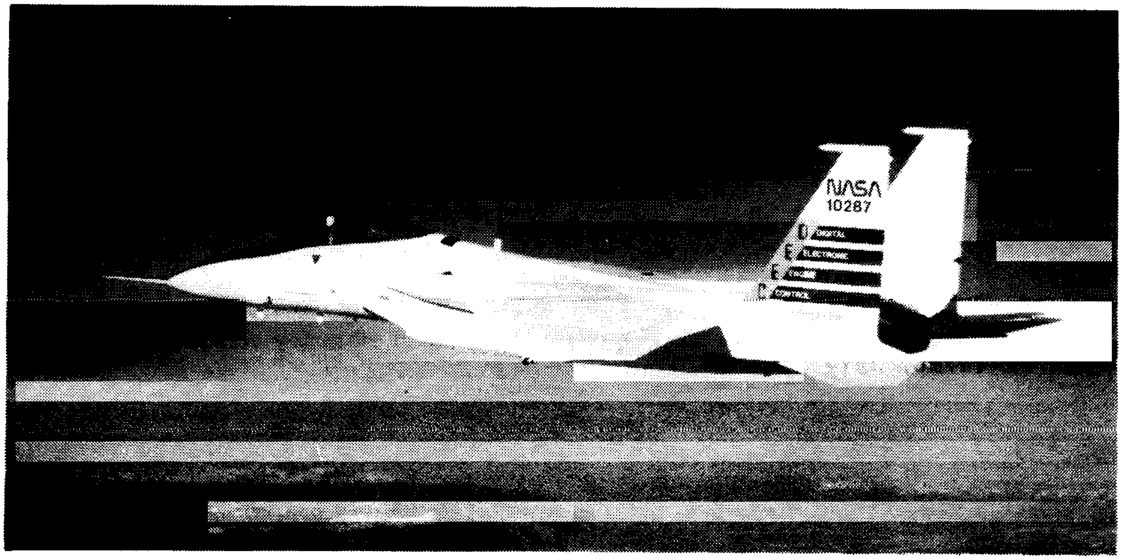
3. Ewen, J. S.; and Walter, W. A.: F100 Engine Model Derivative Program/ Initial Engine Altitude Test Report. Pratt and Whitney Aircraft Report PWA FR-14785, July 1981.




**ECN 17712**

*Figure 1. F-15 airplane used for DEEC test evaluation.*

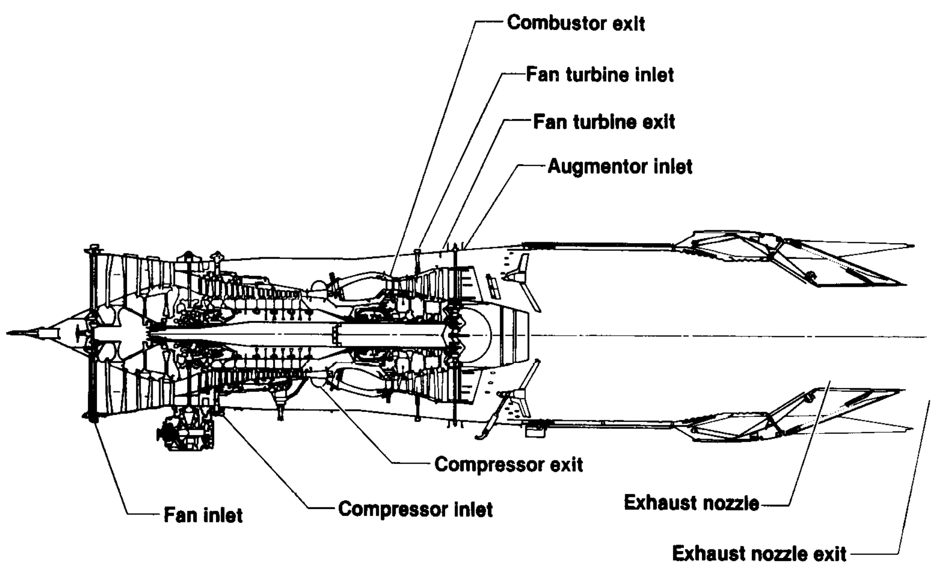



*Figure 2. F100 DEEC test engine.*

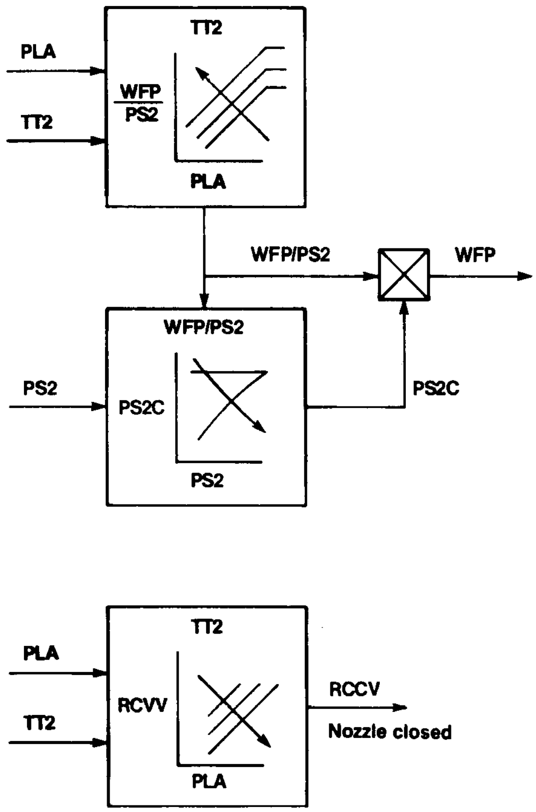
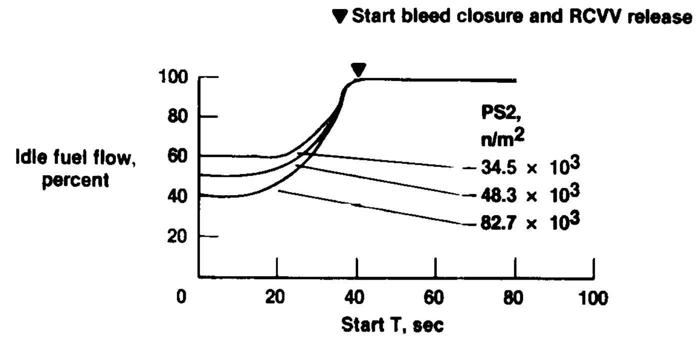
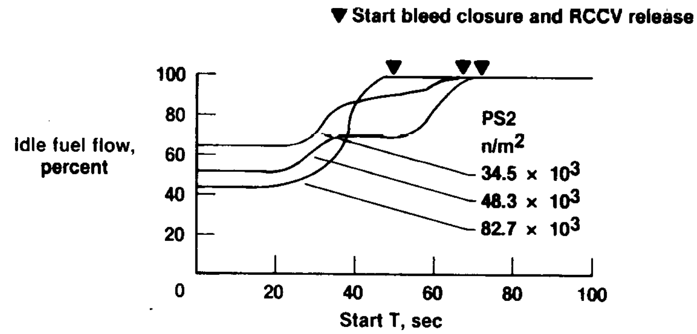



*Figure 3. Secondary engine-control logic.*




*(a) Group I schedule.*




*(b) Group II schedule.*

*Figure 4. SEC air start fuel-flow schedules.*

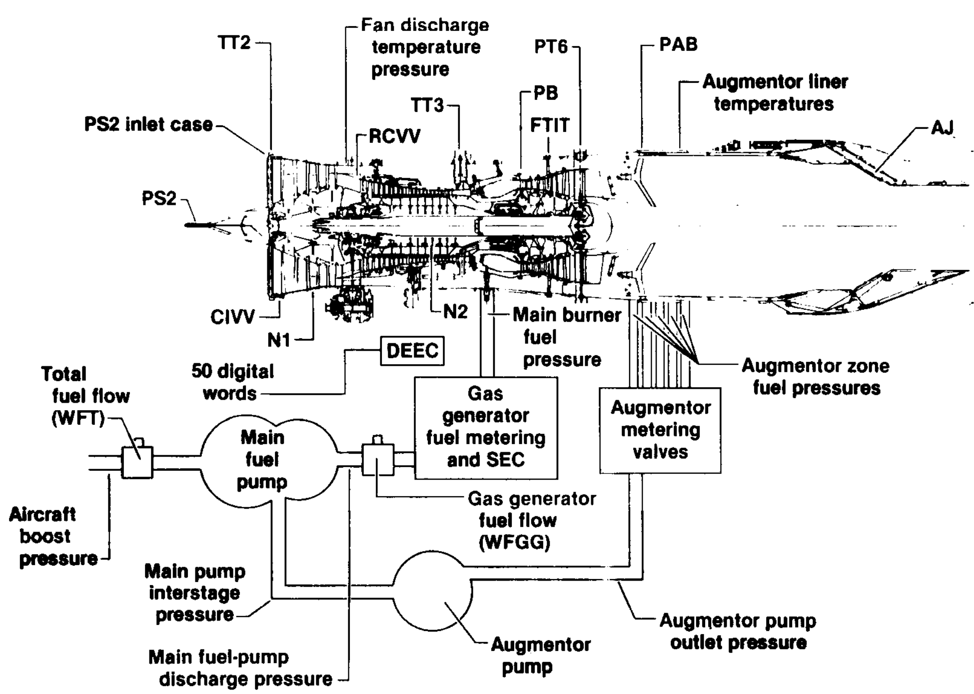
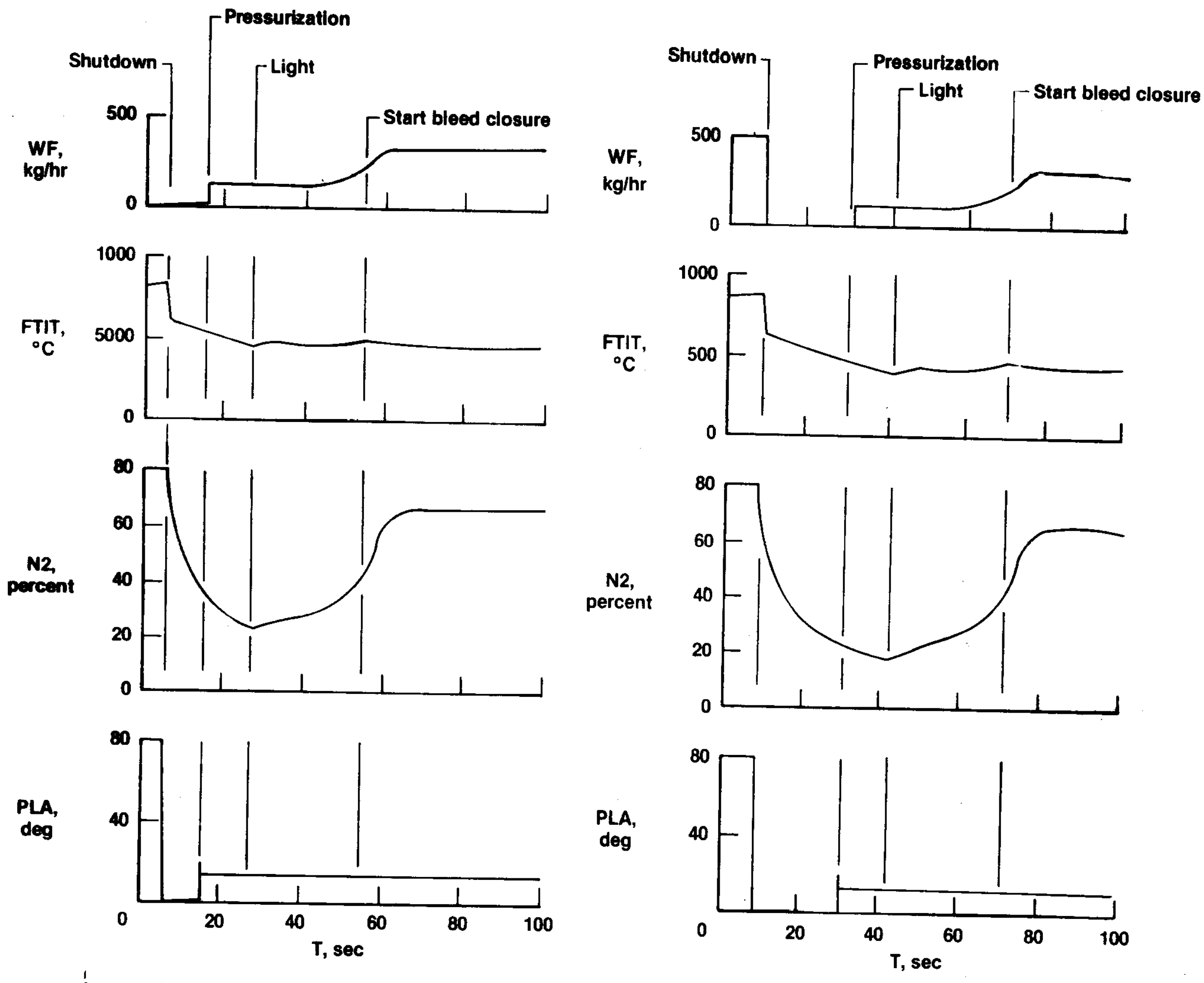


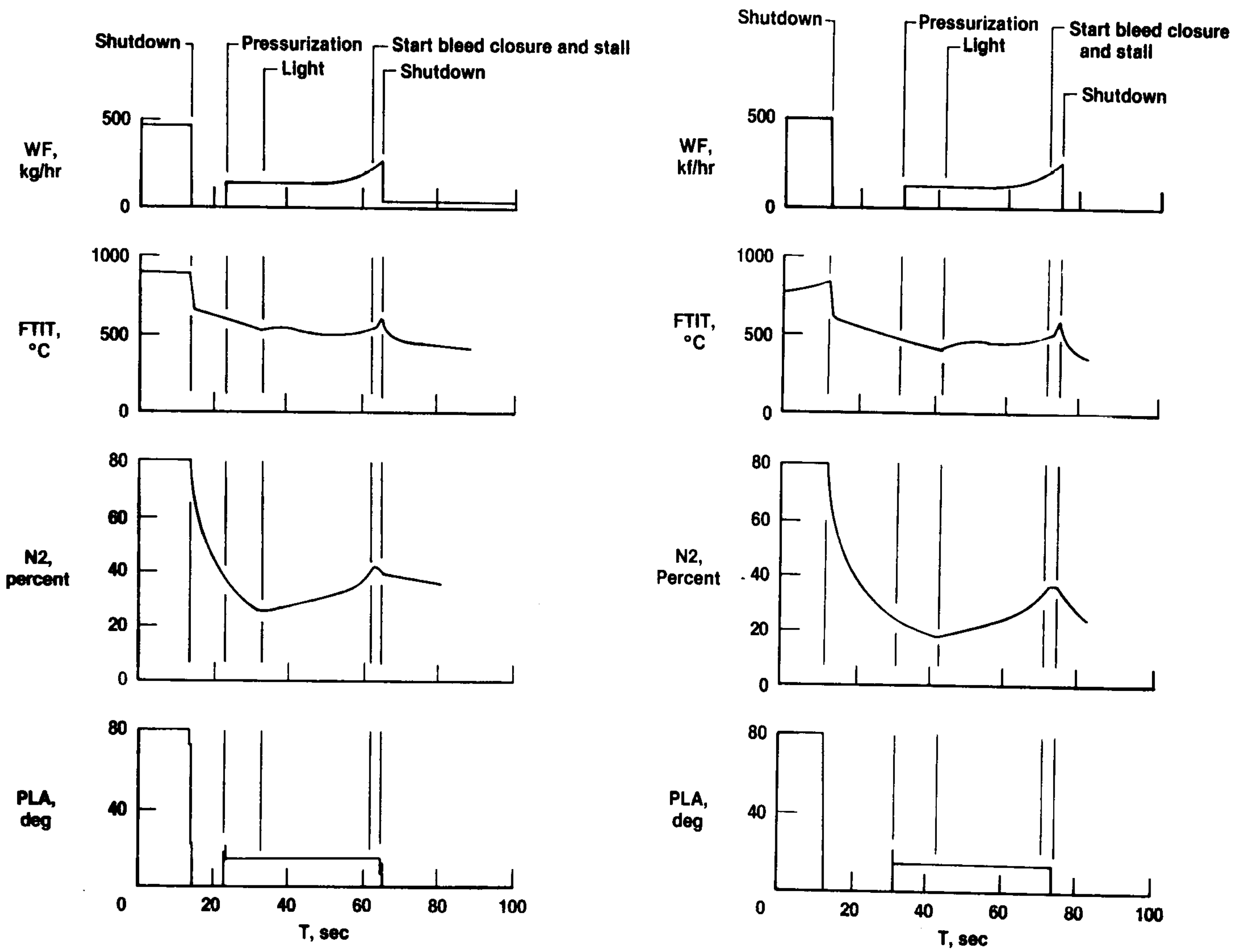

*Figure 5. DEEC test engine fuel system and instrumentation.*




*(a) 40-percent spooldown. PS2 = 6.9 × 10⁴ Pa.*

*(b) 25-percent spooldown. PS2 = 7.1 × 10⁴ Pa.*

*Figure 6. SEC spooldown air start, group I schedules. VC = 310 knots, HP = 4600 m.*




*(a) 40-percent spooldown.*
*PS2 = 6.9 × $10^4$ Pa.*

*(b) 25-percent spooldown.*
*PS2 = 7.0 × $10^4$ Pa.*

*Figure 7. Unsuccessful SEC spooldown air start, group I schedule. VC = 280 knots, HP = 4600 m.*

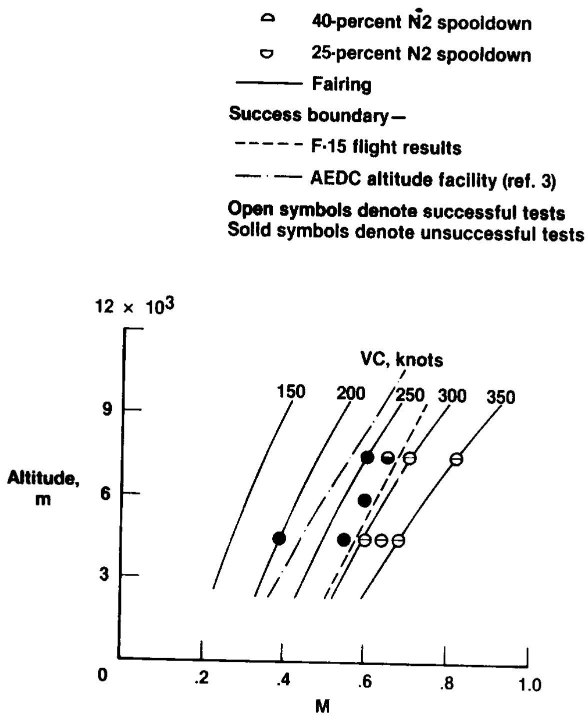
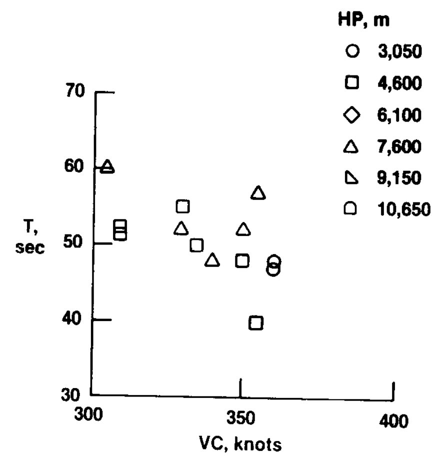
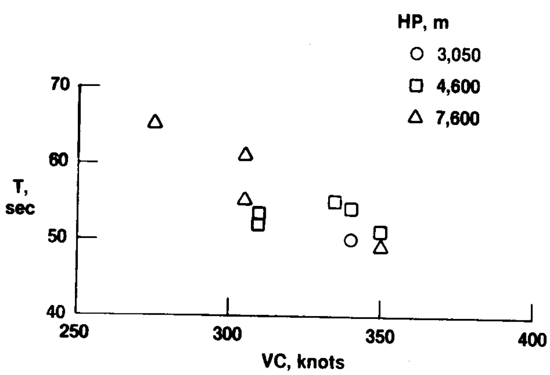



*Figure 8. Summary of group I SEC-mode air starts and success boundaries.*

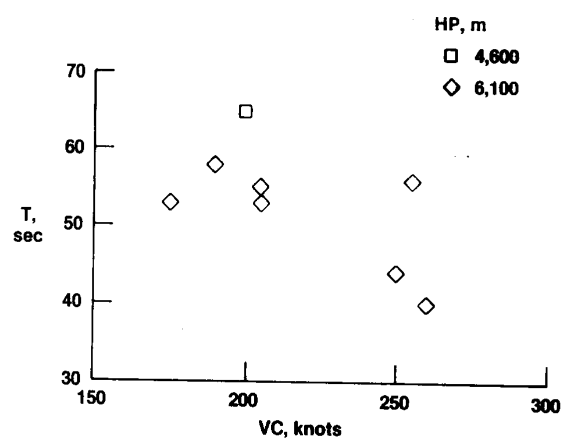



*(b) 25-percent spooldown.*



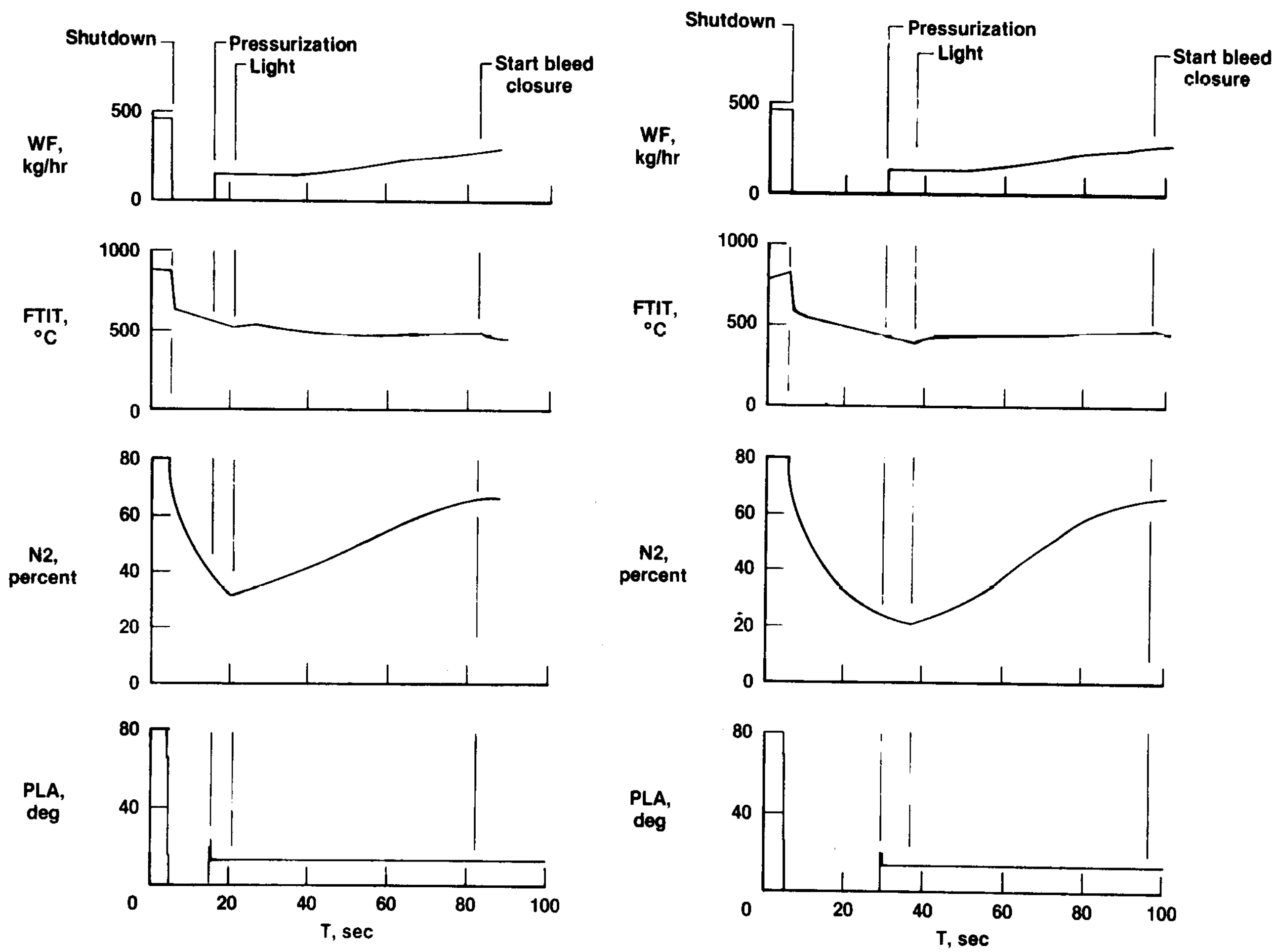

*(a) 40-percent spooldown.*

*Figure 9. Time from pressurization to idle for SEC spooldown air starts. Group I schedules.*




*(c) JFS assisted.*

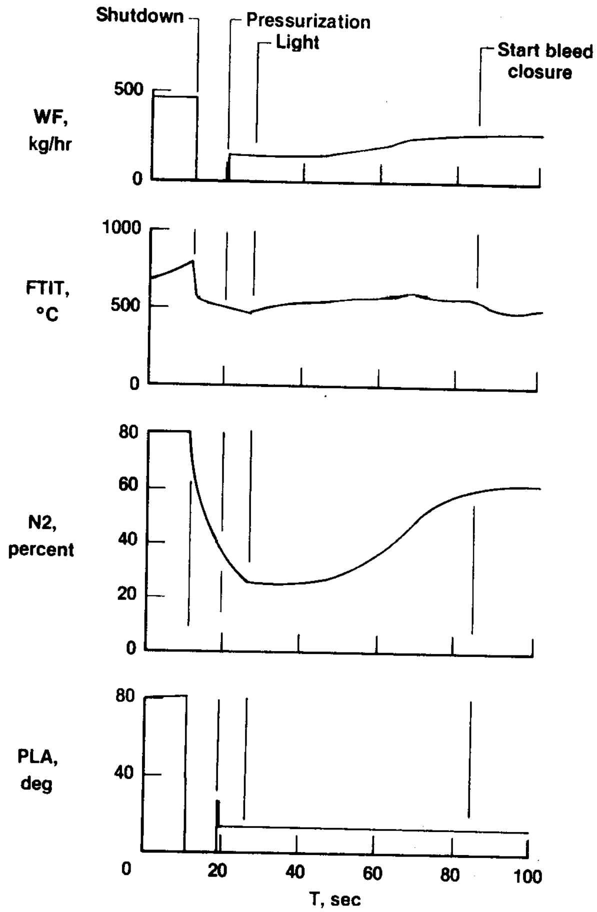
*Figure 9. Concluded.*



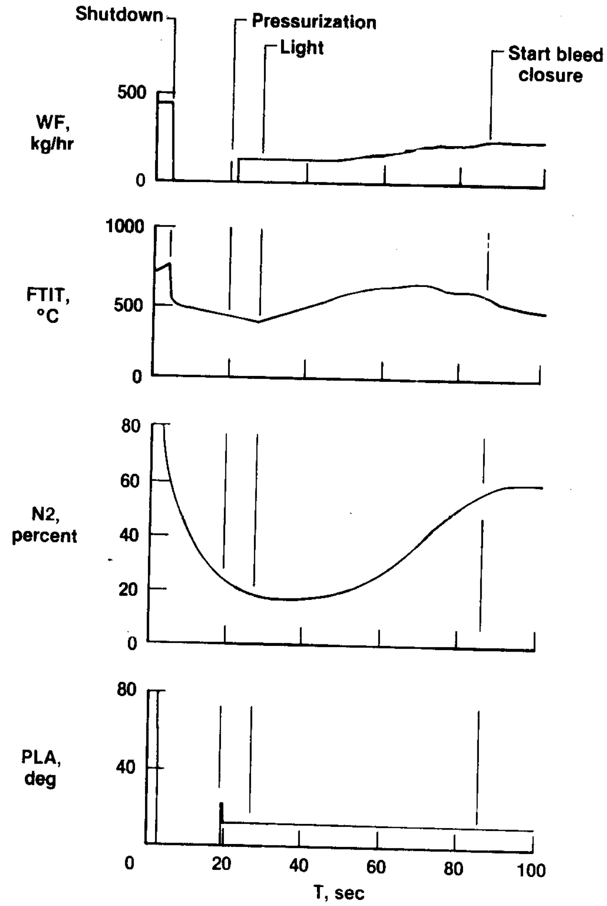

*(a) 40-percent spooldown.*
*PS2 = 6.2 × $10^4$ Pa.*

*(b) 25-percent spooldown.*
*PS2 = 6.1 × $10^4$ Pa.*

*Figure 10. SEC spooldown air start, group II schedules. VC = 300 knots, HP = 6100 m.*




(a) 40-percent spooldown. PS2 = 6.4 × $10^4$ Pa.




(b) 25-percent spooldown. PS2 = 6.2 × $10^4$ Pa.

Figure 11. SEC spooldown air start, group II schedules. VC = 200 knots, HP = 4600 m.

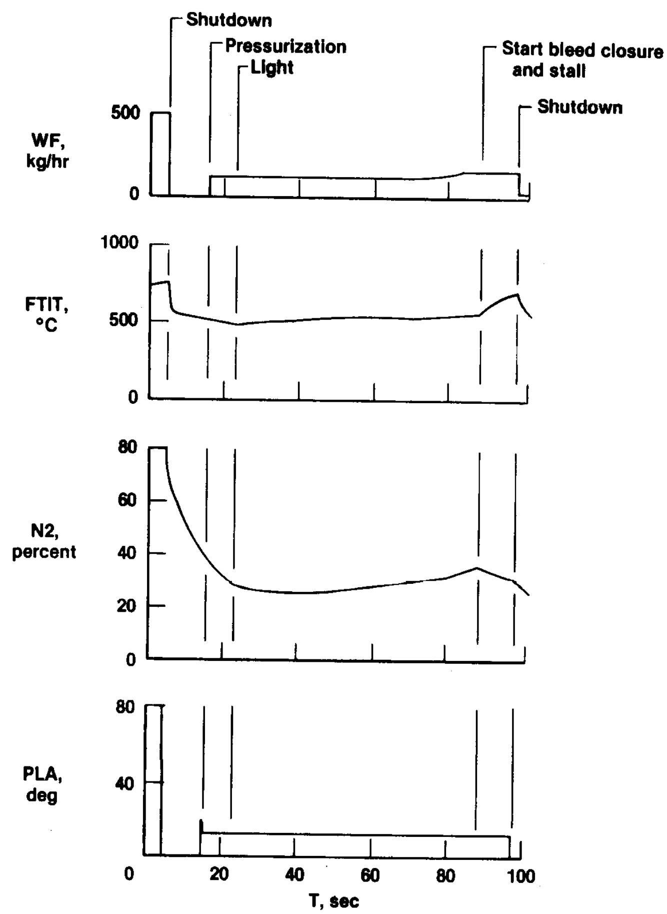



*Figure 12. Unsuccessful SEC 40-percent spooldown air start, group II schedules. VC = 175 knots, HP = 7600 m, PS2 = 4.2 × $10^4$ Pa.*

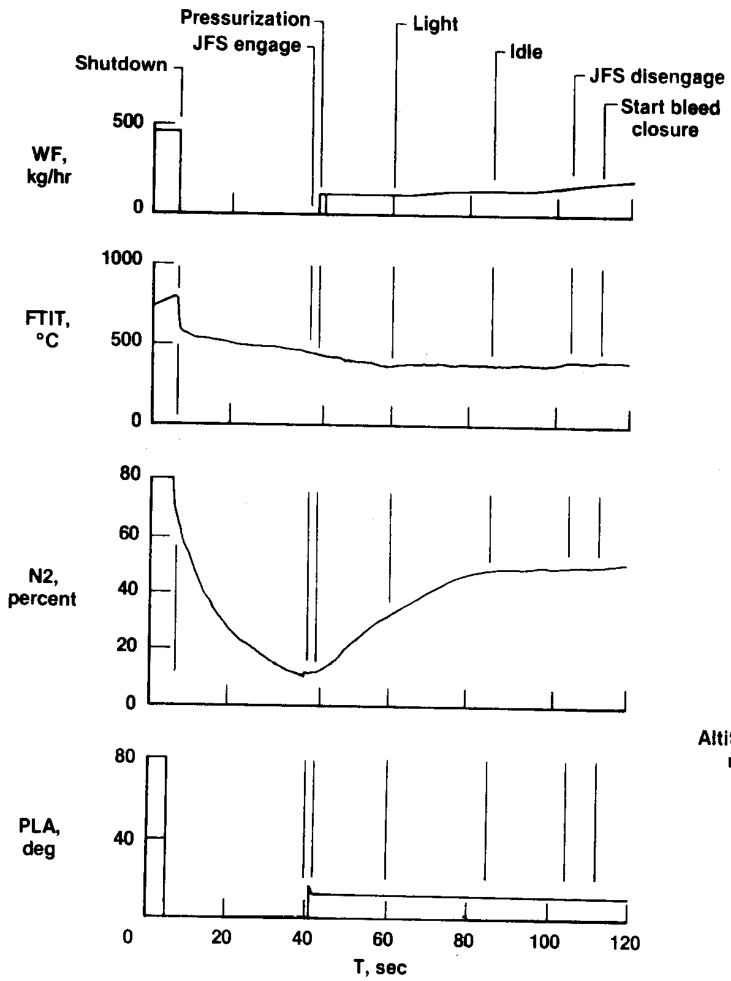



*Figure 13. SEC JFS-assisted air start, group II schedules. VC = 150, HP = 6100 m, PS2 = 5.2 x $10^4$ Pa.*

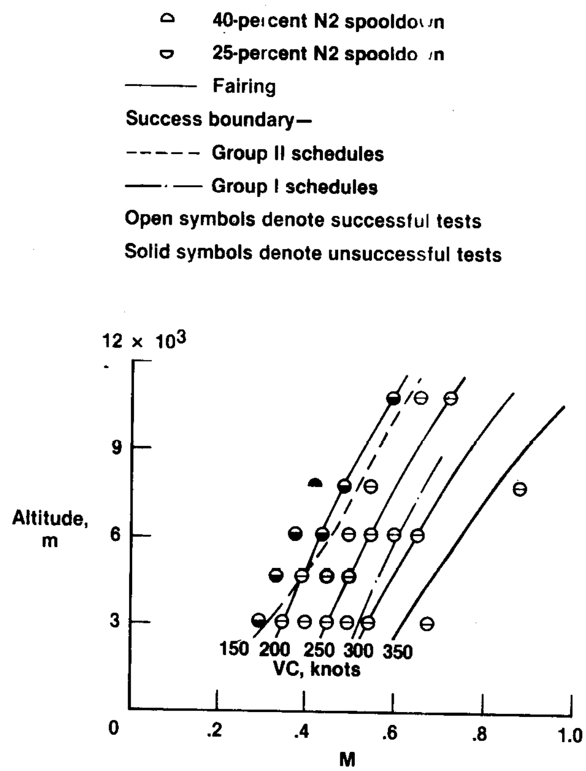
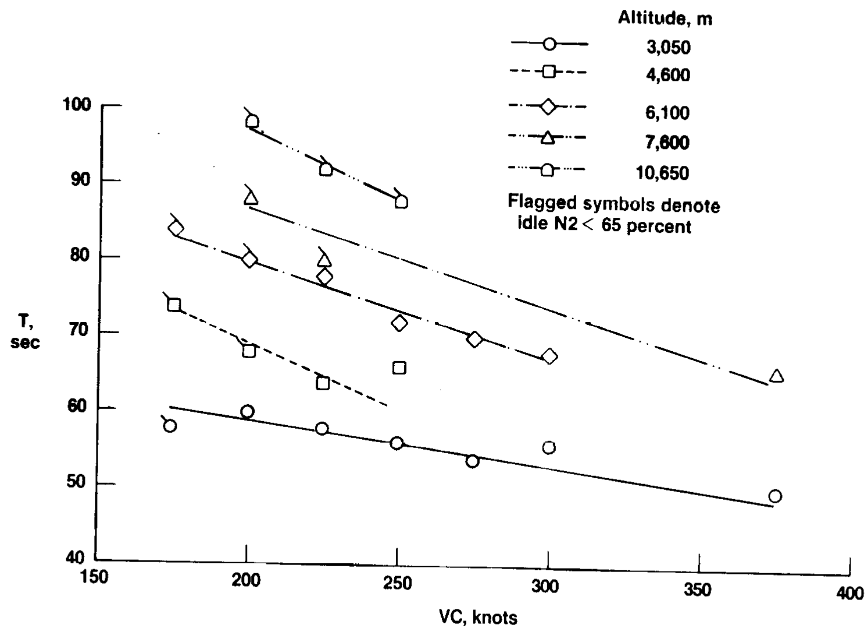
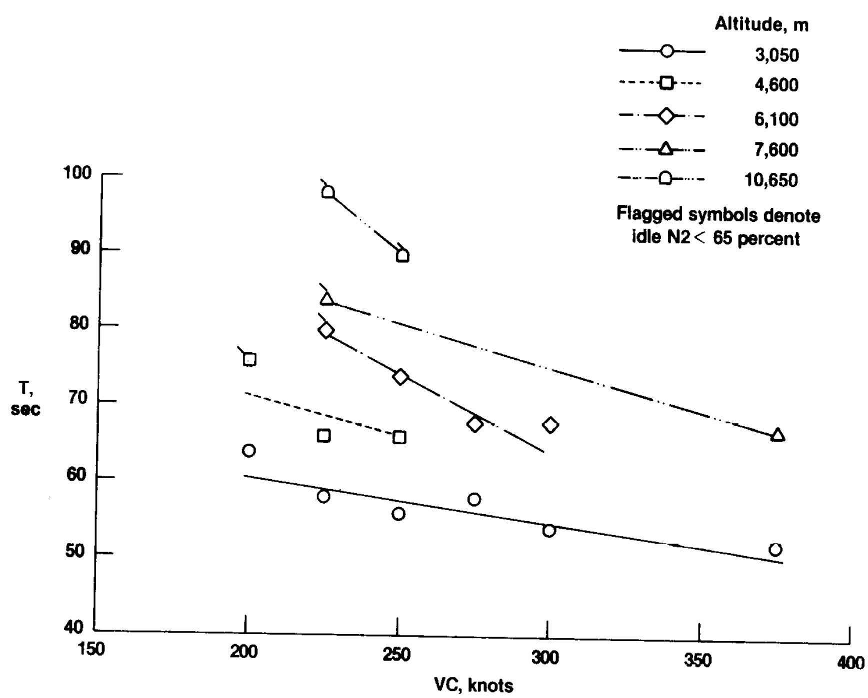



*Figure 14. Summary of group II schedule, SEC-mode air starts and success boundaries.*

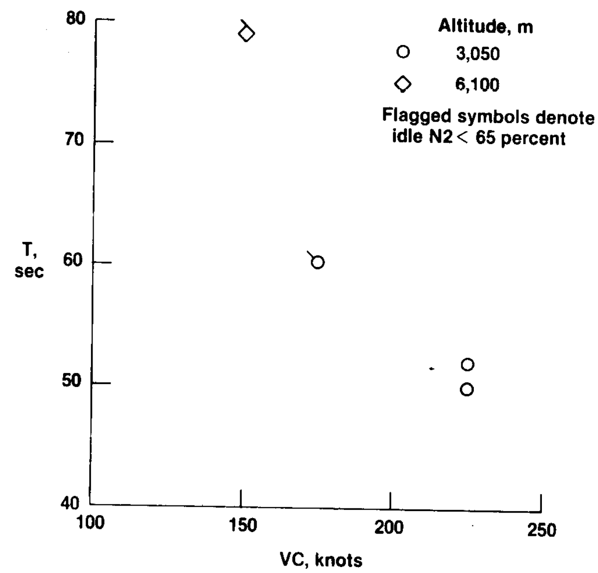



*(a) 40-percent spooldown.*




*(b) 25-percent spooldown.*

*Figure 15. SEC-mode spooldown air starts, group II schedules.*




*(c) JFS assisted.*

*Figure 15. Concluded.*

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16. Abstract


The air-start capability of a secondary engine control (SEC) was tested for a DEEC-equipped F100 engine and installed in an F-15 airplane. Two air-start schedules were tested. The first was referred to as the group I schedule; the second or revised schedule was the group II start schedule.

Using the group I start schedule, an airspeed of 300 knots was required to ensure successful 40- and 25-percent SEC-mode air starts. If N2 were less than 40 percent, a stall would occur when the start bleeds closed 40 sec after initiation of the air start. All JFS-assisted air starts were successful with the group I start schedule.

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